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An fMRI study of human visual cortex in response to spatiotemporal properties of visual stimuli

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Background: The brain response to temporal frequencies (TF) has been already reported, but with no study reported for different TF with respect to various spatial frequencies (SF). ***Materials and Methods:*** fMRI was performed by 1.5T GE-system in 14 volunteers during checkerboard, with TFs of 4, 6, 8 and 10Hz in low and high SFs of 0.5 and 8cpd. ***Results:*** Average percentage BOLD signal change demonstrated the amplitude of the fMRI response to different TFs was maximal in 6Hz for high SF of 8cpd, while, it was maximal at TF of 8Hz for low SF of 0.5cpd. ***Conclusion:*** The results are useful for vision therapy (such as the treatment of Amblyopia) and visual task selecting in fMRI studies. **Iran. J. Radiat. Res., 2006; 3 (4): 191-194**

Keywords: *Spatial frequency, cortical response, temporal frequency, human, fMRI*

INTRODUCTION

The image received on the retina is just a pattern of different light intensities which may constantly. These spatial and temporal variations in the image provide the only information available for visual processing (1, 2). The information associated with the coarser patterns is reflected by low spatial frequencies (LSF), and those with finer patterns mirror high spatial frequencies (HSF)(3). Most visual scenes present temporal as well as spatial information. Temporal changes alone can be important in edge detection as in the case of stationary flickering lights. Temporal frequency (TF) is the scale at which luminance changes occur in the image(2).

Although, the human brain response to a wide range of TFs has been already reported (4-6), but there is no imaging study regarding to different TF with respect to various SFs.

Fox and co-workers (4) studied the stimulus rate dependence of regional cerebral blood flow in human striate cortex by positron emission tomography. The results showed that the rCBF response peaked at 7.8 Hz and then declined. Mentis *et al.* (5) investigated the rCBF response to frequency variation of pattern-flash visual stimulus using PET. They found an rCBF response in the striate cortex with a 7 Hz peak. Kwong *et al.*(6) investigated the stimulation frequency dependence of visual activation by functional magnetic resonance imaging (fMRI). Their results agree with previous positron emission tomography observations and show that the largest MR signal response occurring at 8 Hz. The similar result is found by Thomas and co-workers (7). They showed that the fMRI signal also peaks at a flicker frequency of 8 Hz. Ozus *et al.* (8) studied the rate dependence of human visual cortical responses due to brief stimulation. They found that BOLD signal change increase up to a stimulus frequency of 6 Hz and then stays nearly constant.

In neuro-physiological studies (9-12), it has been suggested that there are multiple visual channels tuned to each of the SF bands and also there is a spatial and temporal frequency selectivity of neurons in visual cortical areas and in the other hand, the psychological studies (13-17) support these results. Therefore, the purpose of this study was to evaluate the visual cortex activity response to TF variations among different SFs.

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MATERIALS AND METHODS

Subjects

The subjects were 14 right-handed healthy volunteers (9 males and 5 females, 19-26 years of age; mean age ± S.D = 22.4 ± 1.8). All subjects had normal visual acuity of 20/20 based on Snellen's fraction in each eye with good binocular vision and normal visual field based on confrontation test. There has not been any history of visual loss or neurologic problems in subjects. The volunteers were informed consent before participating in this study and written consents were obtained from each of them.

Visual stimuli

We used square-wave reversal checkerboard visual stimulation with different temporal frequencies of 4, 6, 8 and 10 Hz in two stats of low SF of 0.5 and high SF of 8 cycles/degree (cpd). Visual tasks were provided by "Presentation" software (version 0.60) and projected by a video projector on a screen. The subjects could have looked at visual stimuli through the non-magnetic mirror in front of their eyes during imaging process. All lights were turned off in the MRI room and the room was made as dark as possible, so that, the visual tasks were just only visual stimulation that the subject could look. The mean luminance of the entire checkerboard was 161.4 cd/m^2 and the black and white check contrast was 96%. The visual angle of the stimulus subtended 11.2° horizontally and 8.3° vertically.

Data acquisition

Experiments were performed with a GE 1.5 T MRI system equipped with echo-planar (EPI) acquisition (TR = 3300 ms, TE = 29 ms, flip angle = 90°, matrix size = 64×64, number of slices=8, fov = 240 × 240 mm^2, voxel size of 3.74×3.74×8.0mm^3) sensitive to BOLD contrast. The data were acquired in three steady state trials per subject in a stimulus "on" for 30; sec and "off" for 30 sec, i.e., 80-sec cyclic block design. Each state of spatial and temporal frequency was presented over three cycles for a total of 3 min per trial. The functional images were acquired in an axial orientation parallel to anterior commissure-posterior commissure (AC-PC) line. A functional volume composed of 8 slices with thickness of 8 mm and spacing of 2 mm was imaged for 480 times (60 image per slice) per trial.

Data analysis

The activation map was created using the data obtained from the block designed fMRI study. Pixels whose correlation coefficient value was above a threshold of 0.33, at significant level P<0.01 were considered activated. After color-coding, these superposed on corresponding anatomical images. The average percentage bold signal change for all activated pixels within the occipital lobe, multiplied by the total number of activated pixels within the occipital lobe, was used as the criteria for the strength of the fMRI signal at each state of TF and SF.

RESULTS

The results show that the BOLD signal changes with TF variations of visual stimulation. The maximum BOLD signal change happens in TF of 8 Hz for visual stimuli with low SF of 0.50 cpd whereas this change happens in TF of 6 Hz for stimuli with high SF of 8 cpd. The BOLD signal change in high SF is smaller than the one low SF for all TFs.

The functional maps due to visual stimulation in maximum bold response to TF of 8 Hz in LSF state of 0.5 cpd and to TF of 6 Hz in HSF state of 8 cpd for one of the subjects, superimposed on corresponding anatomical image is shown in figure 1.

Averaged percentage BOLD signal change for fourteen-subjects as a function of TF in two states of LSF of 0.50 cpd and HSF of 8 cpd is illustrated in figure 2.

DISCUSSION

This study shows that in low SF of 0.50 cpd, the maximum BOLD signal change happens in TF of 8 Hz and this result is

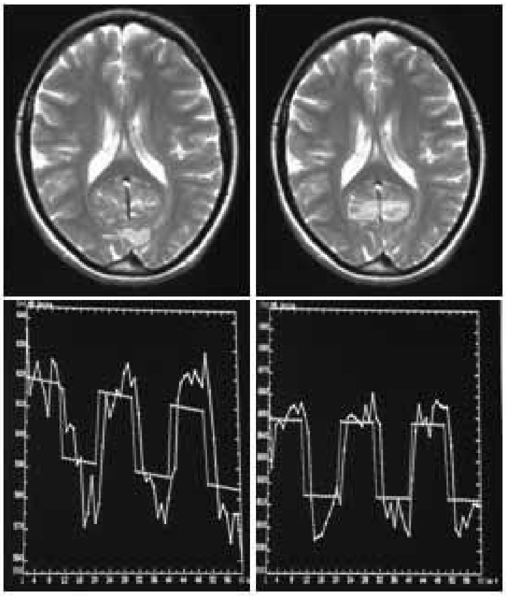

Figure 1. Comparison of activation area and BOLD signal with the maximum response at temporal frequency of 8 Hz in LSF of 0.5 cpd (right picture), and 6 Hz in HSF of 8 cpd (left picture)

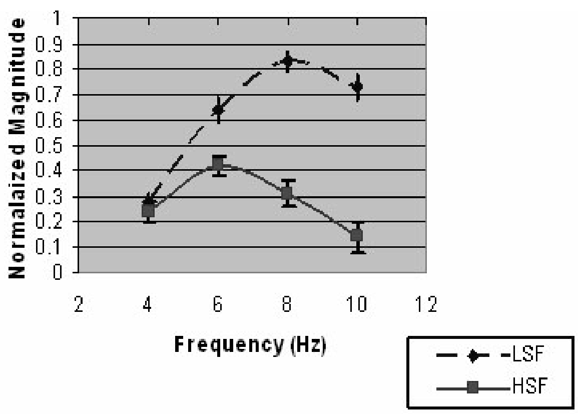

Figure 2. Comparison of the fourteen-subject averaged fMRI signal strengths as a function of TF in two stages of LSF of 0.5 cpd and HSF of 8 cpd. (The signal has been normalized to its largest value and the error bars representing the standard error of mean)

consistent with many previous reports during light-flash stimulations(4-7) or reversal checkerboards of low SF (18).

In addition our results demonstrate that change in the bold response with temporal frequency is also dependent to the spatial frequency, so that the amplitude of the fMRI response to different temporal frequencies was maximum in 8 Hz only for low SF of 0.50 cpd, whereas, it was maximum at temporal frequency of 6 Hz for high SF of 8 cpd. In this approach, the amplitude of the fMRI response at different temporal frequencies was significantly dependent on spatial frequency components of the viewing image (i.e. checkerboard). Furthermore, spatial frequency aspect of the viewing checkerboard affects the response of functional activity area in brain cortex to temporal frequency variation.

Results in this study agree with the results of animal invasive neuro-physiological studies (9-12) that show spatial and temporal frequency selectivity of neurons in visual cortical areas.

In this study, during high SF of 8 cpd, the maximum BOLD signal was produced in the TF lower than 8 Hz, i.e., in 6 Hz; this result is consistent with the concepts of 'sustained neural channel'(high SFs associated with lower TFs) and 'transient neural channel'(low SFs associated with higher TFs) (19).

The other reason for this result may be that the higher the velocity (or TF) the lower the SFs to which the cortical visual cell is tuned-(20), i.e., with increasing TF from 6 to 8 Hz, those cells responding to SF of 8 cpd showed a pronounced reduction in response to that SF and cause the decreasing in BOLD signal.

In regard to psychophysics and many other studies, it has been suggested that visual perception is mainly based on spatial frequency (Fourier) analysis of the image. This analysis starts with processing low SFs, followed by processing HSF. So that spatial frequency is an important factor in evaluation of responses of brain to other physical and psychophysical aspects of vision such as temporal frequency.

CONCLUSION

The results of this study is very useful in selecting an optimum spatial frequency with respect to a proper choice of temporal frequency as practiced during various vision therapy methods such as amblyotherapy and visual task selecting in fMRI studies. Visual tasks planed in fMRI studies can also benefit the advantage of these physical effects in brain cortical responses.

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